

Neutron study update with 1.5cm cube

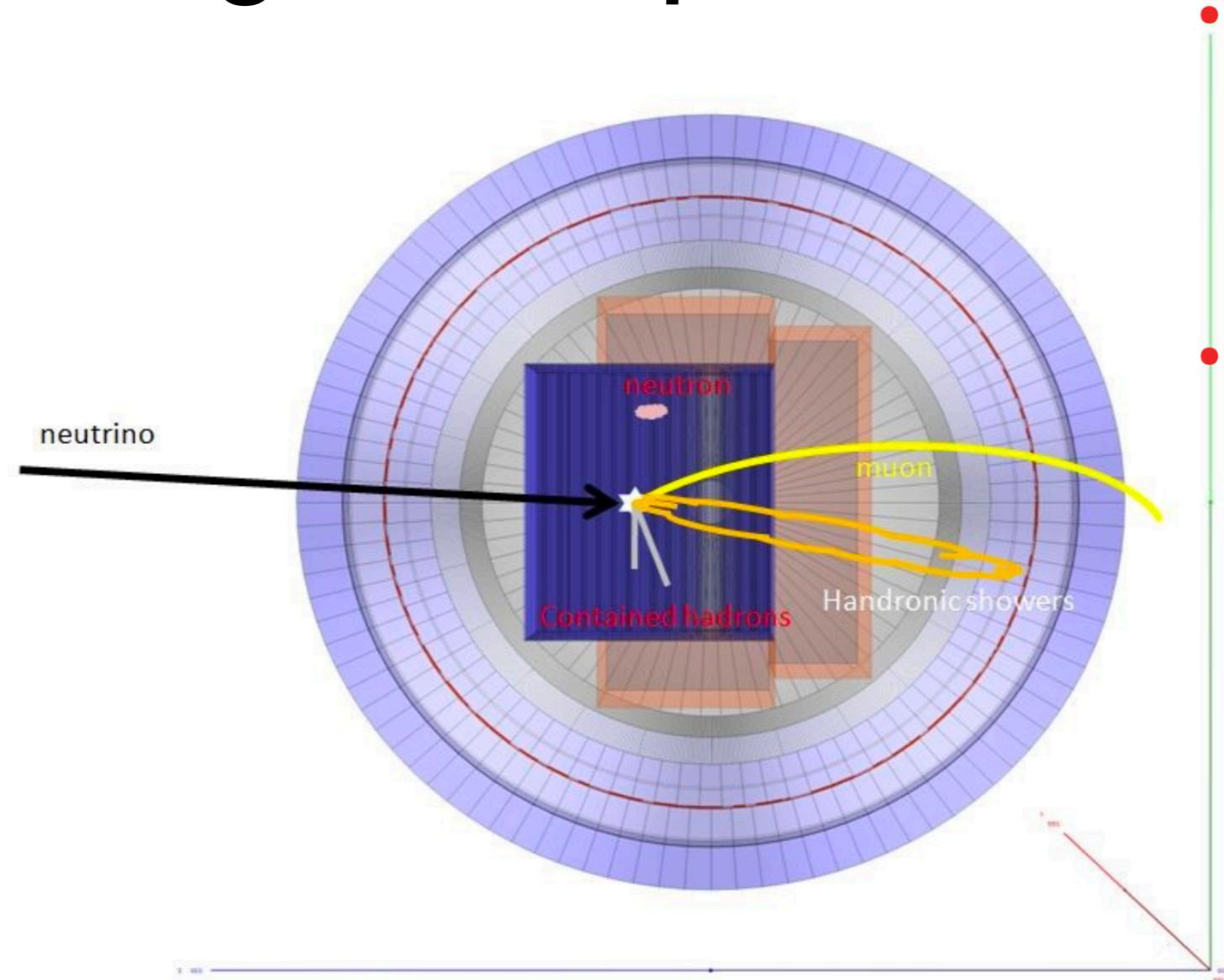
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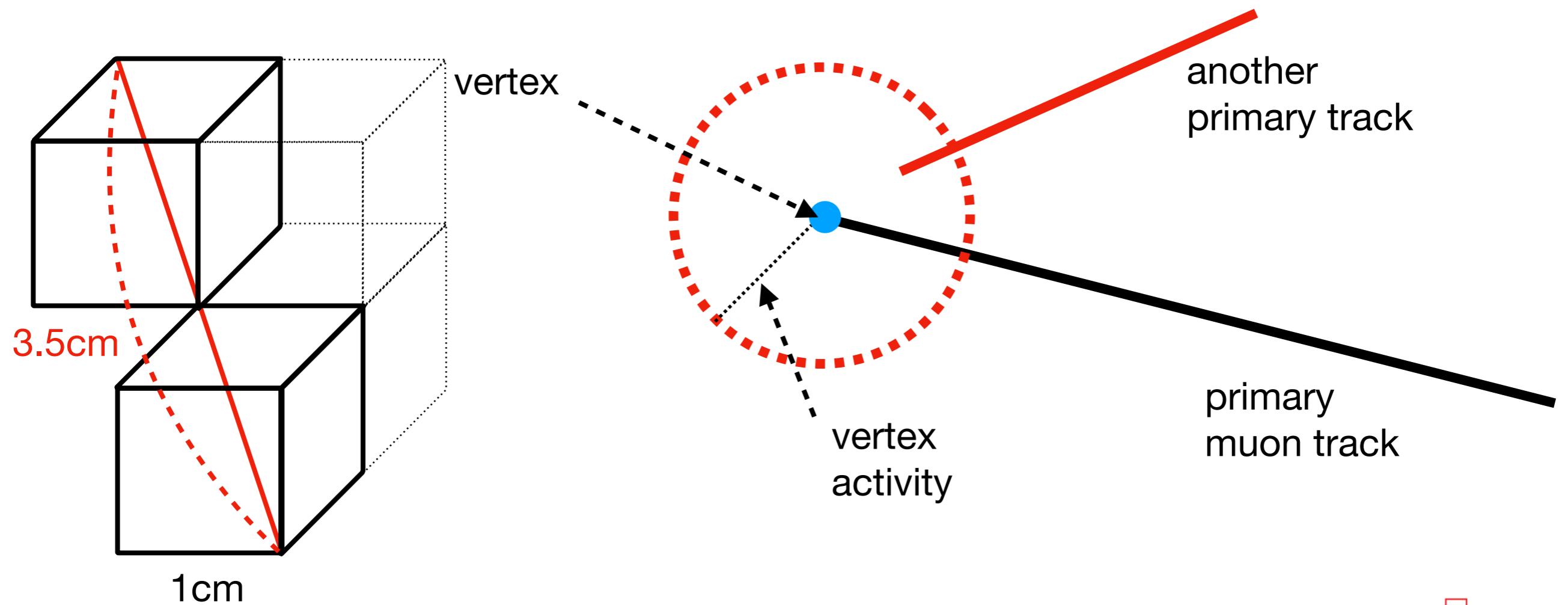
3DST in SAND signal sample selection



- We are looking at anti neutrino charged current event (simulation data) inside 3DST.
- Channel selection based on number of pions: start from the CC0pi (dominant in low- ν sample) and pion production samples will be considered.

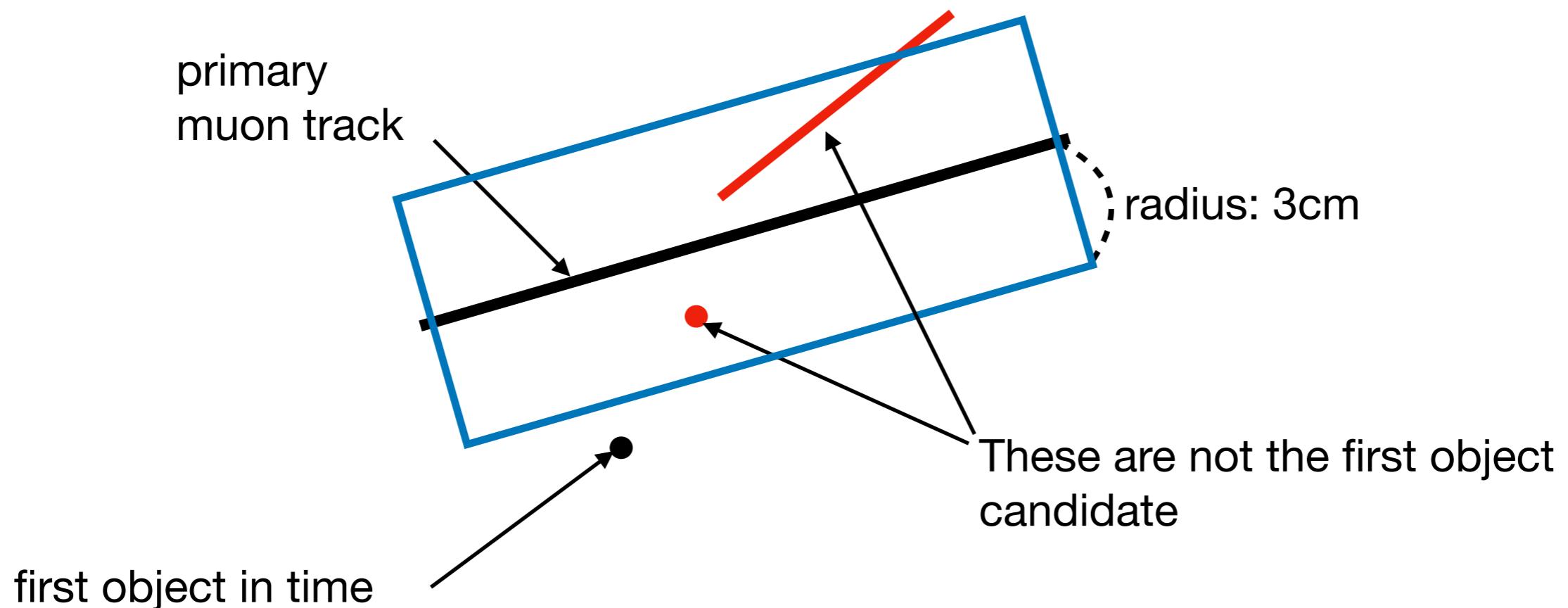
Selection of channel

- Neutrino interaction vertex is the starting point of primary muon track.
- After selecting the vertex, we count how many tracks are inside vertex activity (4cm).
- We selected 1 track channel (intended for CC0 π).



Definition of first object

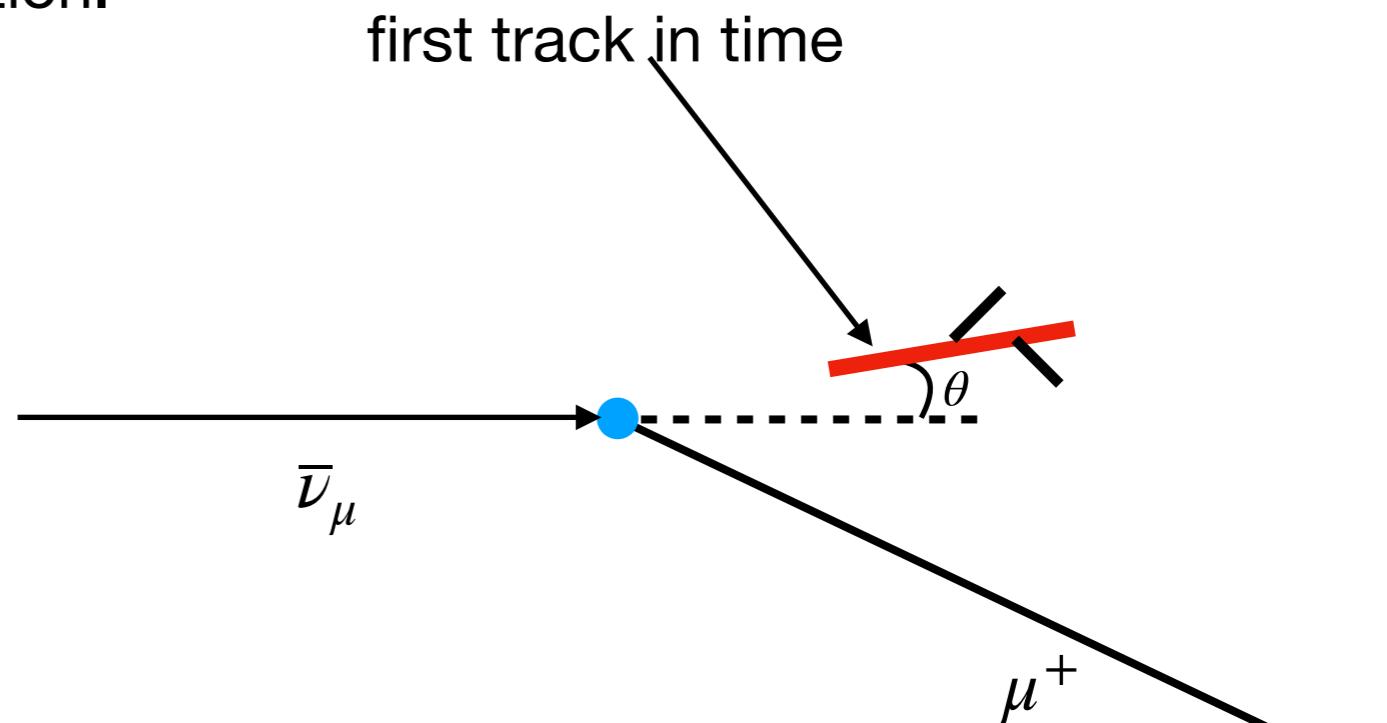
- After selecting channel, we look at the first isolated object in time.
- The first object should be apart from primary muon track more than 3cm (isolated).
- The first object can be track or cluster, we treat track and cluster separately.



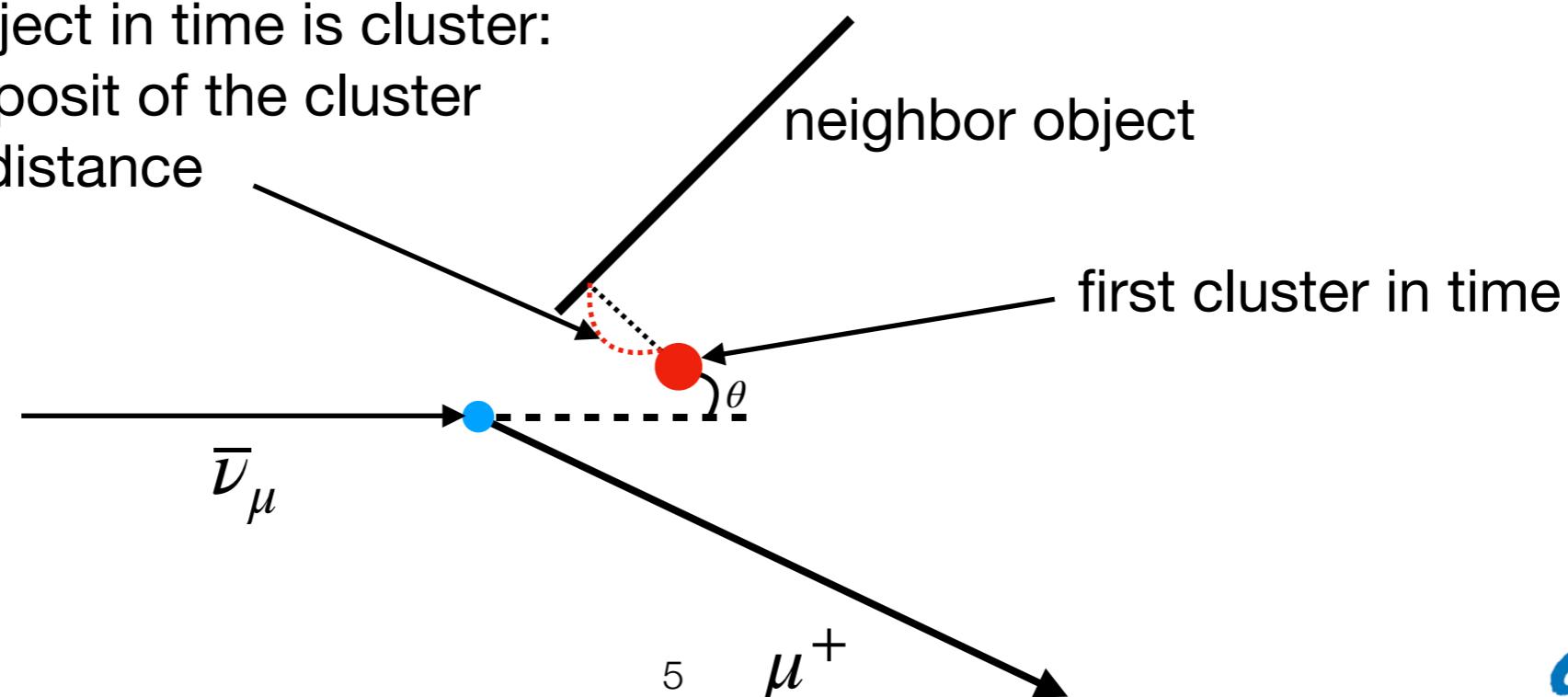
Definition of variables

- We defined variables for signal selection.

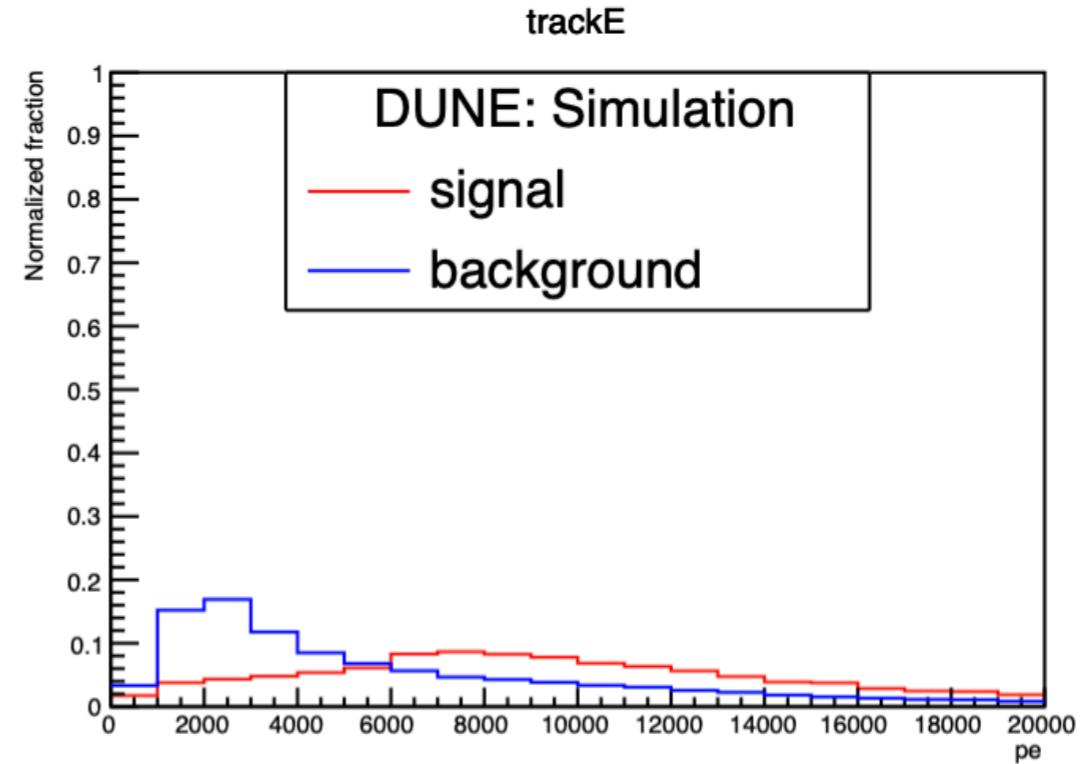
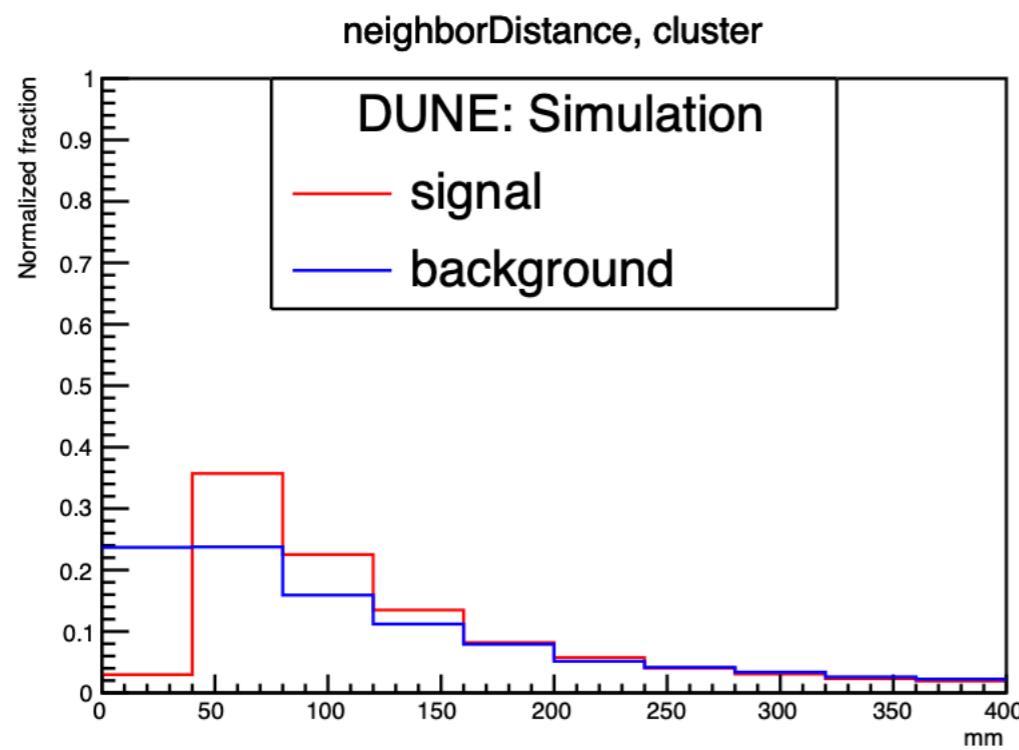
- If the first object in time is track:
 - 1) energy deposit of the track
 - 2) number of branches
 - 3) track length



- If the first object in time is cluster:
 - 1) energy deposit of the cluster
 - 2) neighbor distance

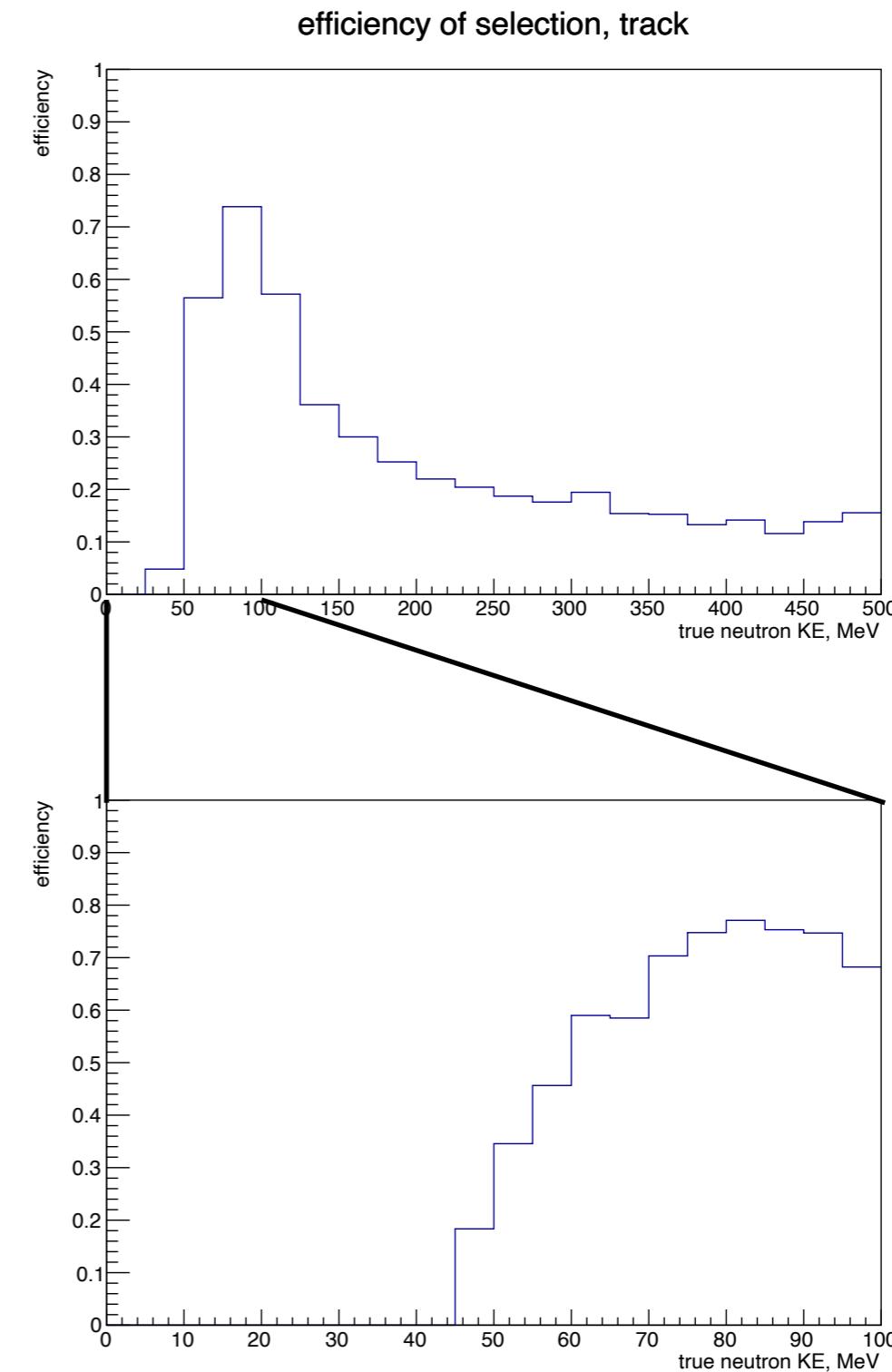
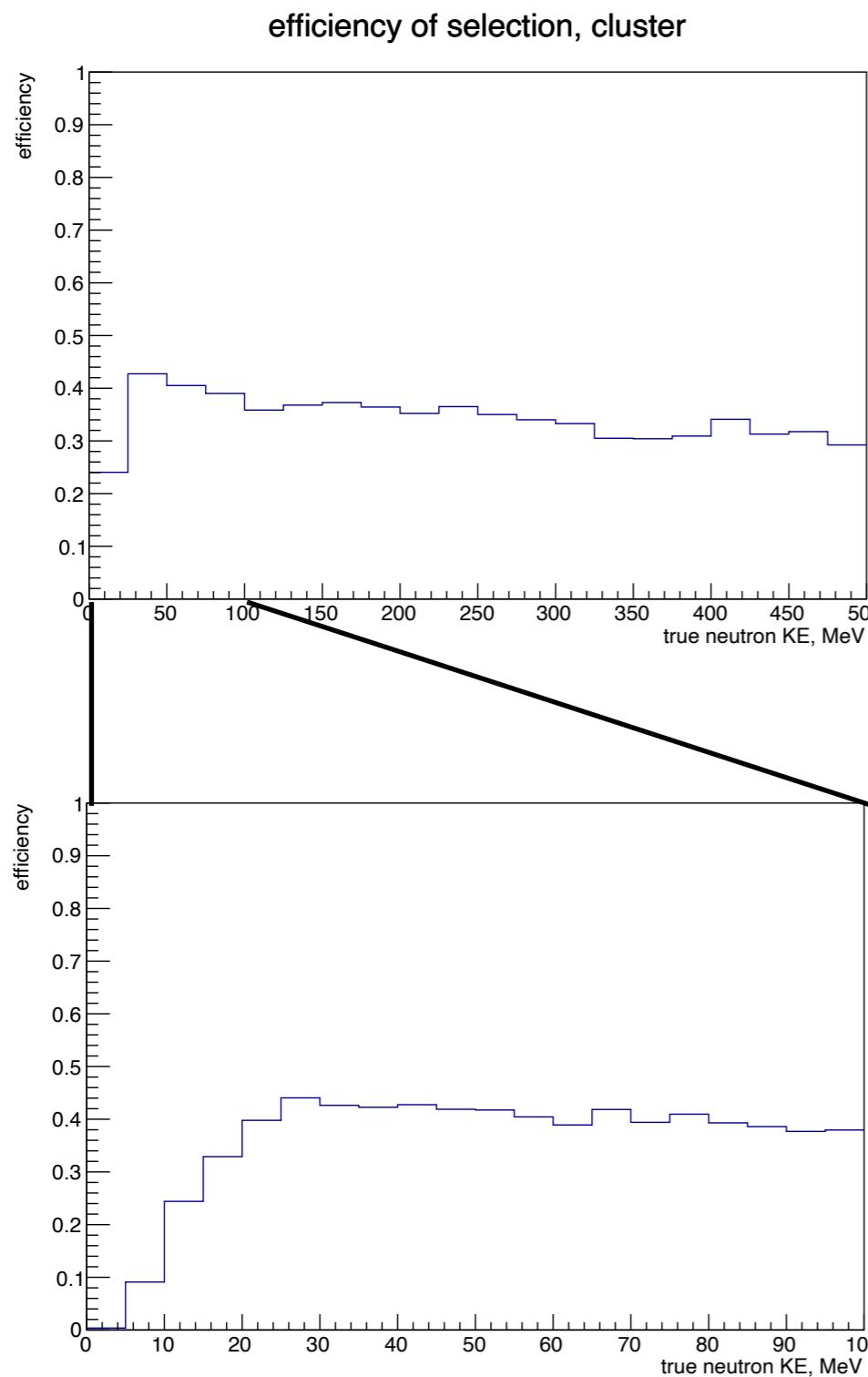


Signal selection



- Cut is series of simple 1D cuts :
 - track : energy deposit + number of branch + track length
 - cluster : energy deposit + neighbor distance
- Track purity 90% efficiency 24.8%, cluster purity 90% efficiency 35%.
- Combined efficiency is 33.1%, we are checking neutron phase space.
- After selecting low ν , the final selection efficiency is 25.4%. (deno = 1track)

Phase space check



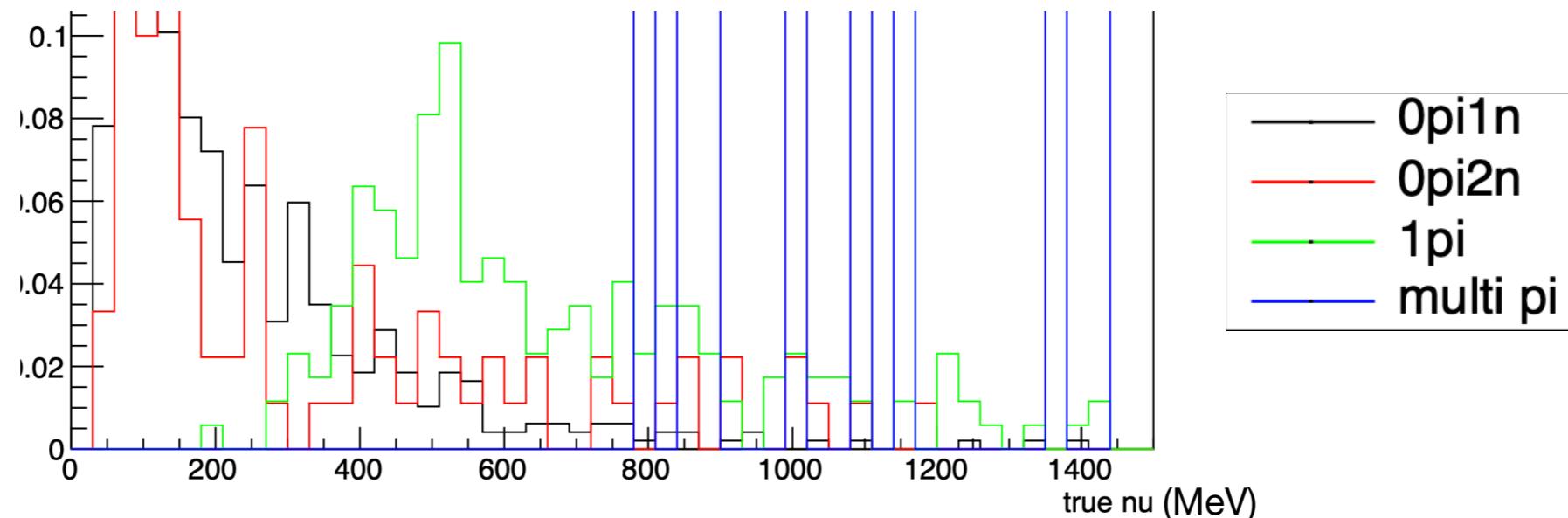
number of cluster event : number of track event = 6 : 1

Low ν channel

- The inclusive charged current scattering cross section for neutrinos can be expressed in terms of neutrino energy (E_ν), the energy transferred to the nucleus (recoil energy of ν), and the Bjorken scaling variable (x) as

$$\frac{d\sigma}{d\nu} = \frac{G_F^2 M}{\pi} \int_0^1 \left(F_2 - \frac{\nu}{E_\nu} [F_2 \mp xF_3] + \frac{\nu}{2E_\nu^2} \left[\frac{Mx(1-R_L)}{1+R_L} F_2 \right] + \frac{\nu^2}{2E_\nu^2} \left[\frac{F_2}{1+R_L} \mp xF_3 \right] \right) dx$$

- If $\nu \ll E_\nu$, ν/E_ν , ν/E_ν^2 and ν^2/E_ν^2 are small, yielding a cross section that is approximately constant as a function of neutrino energy, shape of the neutrino spectrum for $\nu < \nu_0$ can be used to determine the shape of neutrino flux as a function of E_ν



Normalized fraction of reconstructed ν for each interaction channel

- $\nu < 200$ MeV region is mostly 0pi interaction.

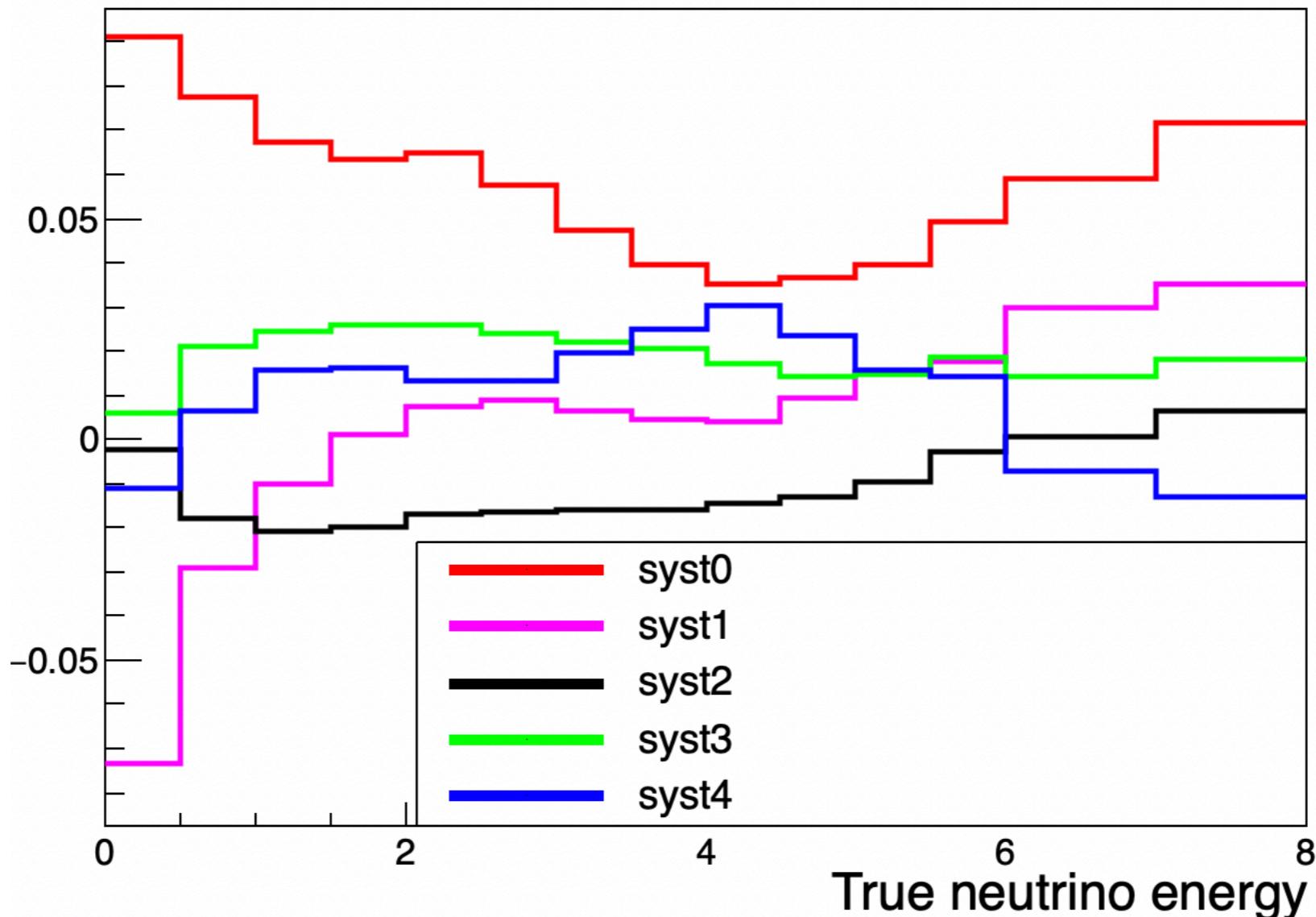
Fitting framework

- We want to see how much selected CC0 π low v sample can constrain the flux uncertainty.
- We have 256 principal component vectors of flux systematic uncertainty from beam line and used the first 10 of them.
- We developed simple χ^2 fitting framework.

$$\bullet \quad \chi^2 = \sum_{i=0}^{N_{E_\nu}} \frac{\left(data_i - [p_i(f_0 \dots f_9) + B] \right)^2}{\sigma_{i,stat}^2 + \sigma_{i,syst}^2} + \sum_{i=0}^9 \frac{(f_{i,CV} - f_i)^2}{\sigma_{f_i}} + \frac{(B_{CV} - B)^2}{\sigma_B}$$

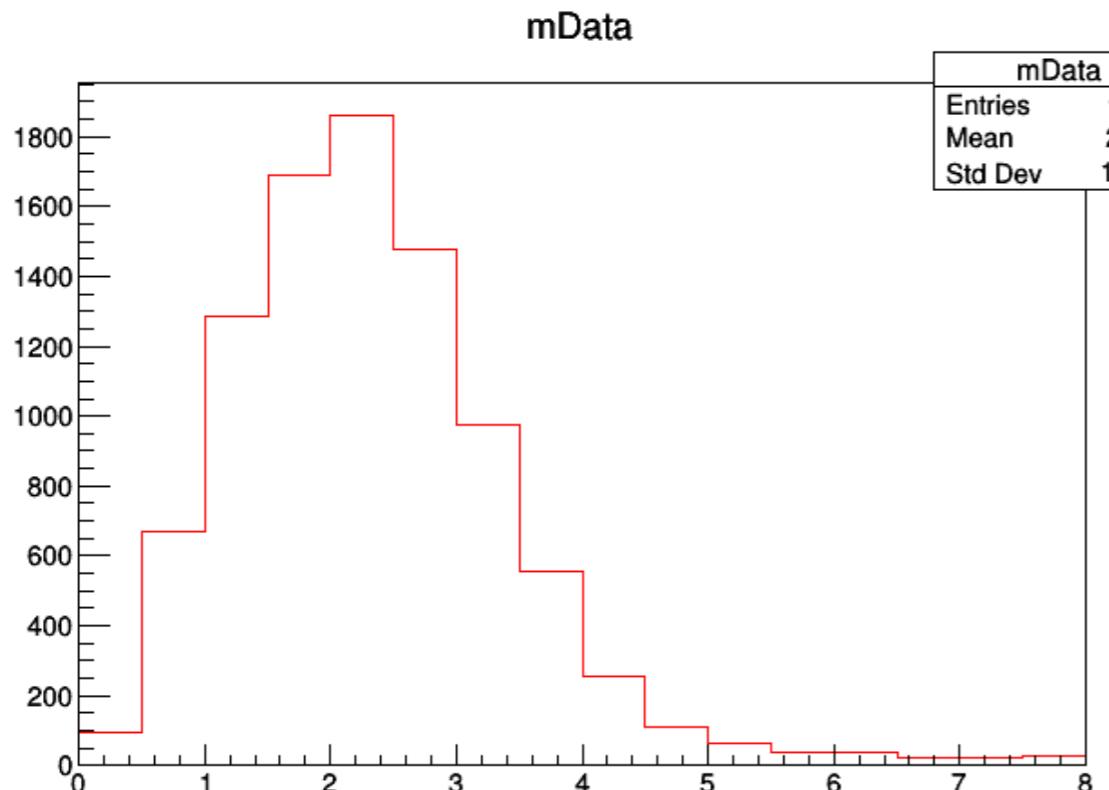
- data : selected CC0 π sample, 90% signal + 10% background.
- prediction : with flux systematic uncertainties, 90% (signal $\pm \Delta$ signal) + 10% (background $\pm \Delta$ background),
- $p_i(f_0 \dots f_9)$: signal prediction with flux systematics (0 ~ 9)
- B : background prediction, used 100% error
- σ_{syst} : low v cross section uncertainties
- CV : central value

Flux systematics

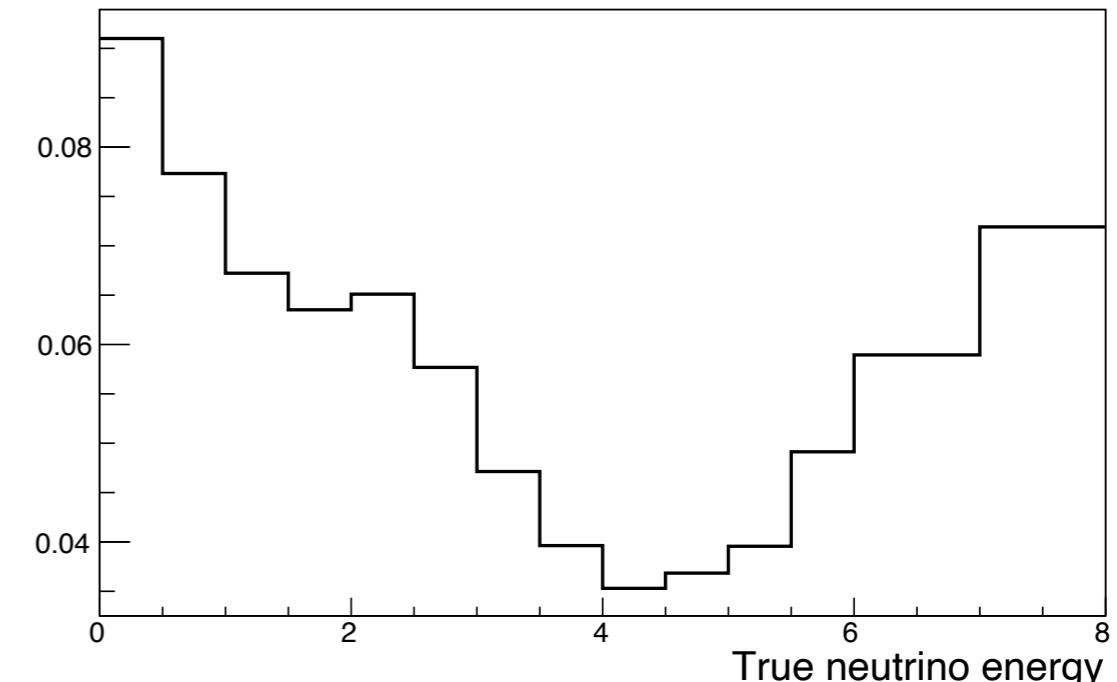


- There are a large number of beam line uncertainty, using principle component can reduce the number of parameters in the framework.
- Principal component 1σ uncertainty from the flux prediction

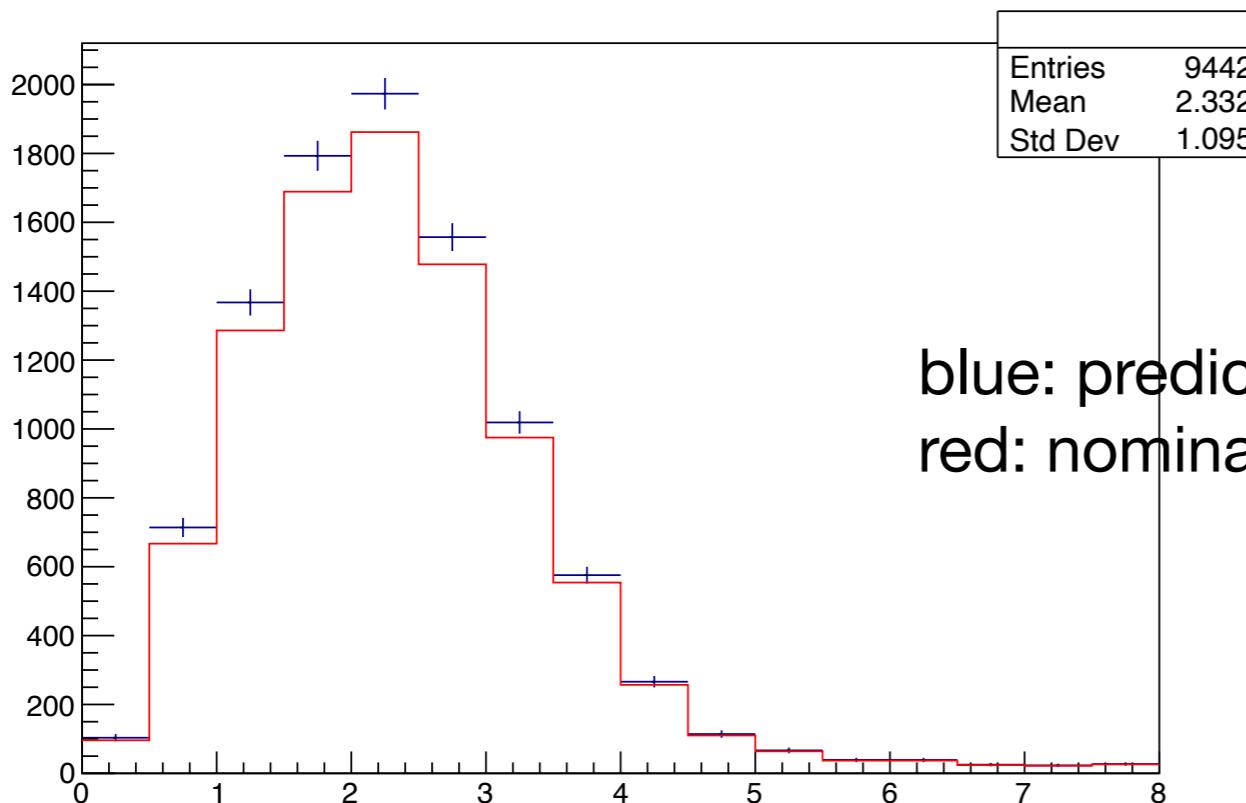
validation of framework



nominal reco E_ν spectrum

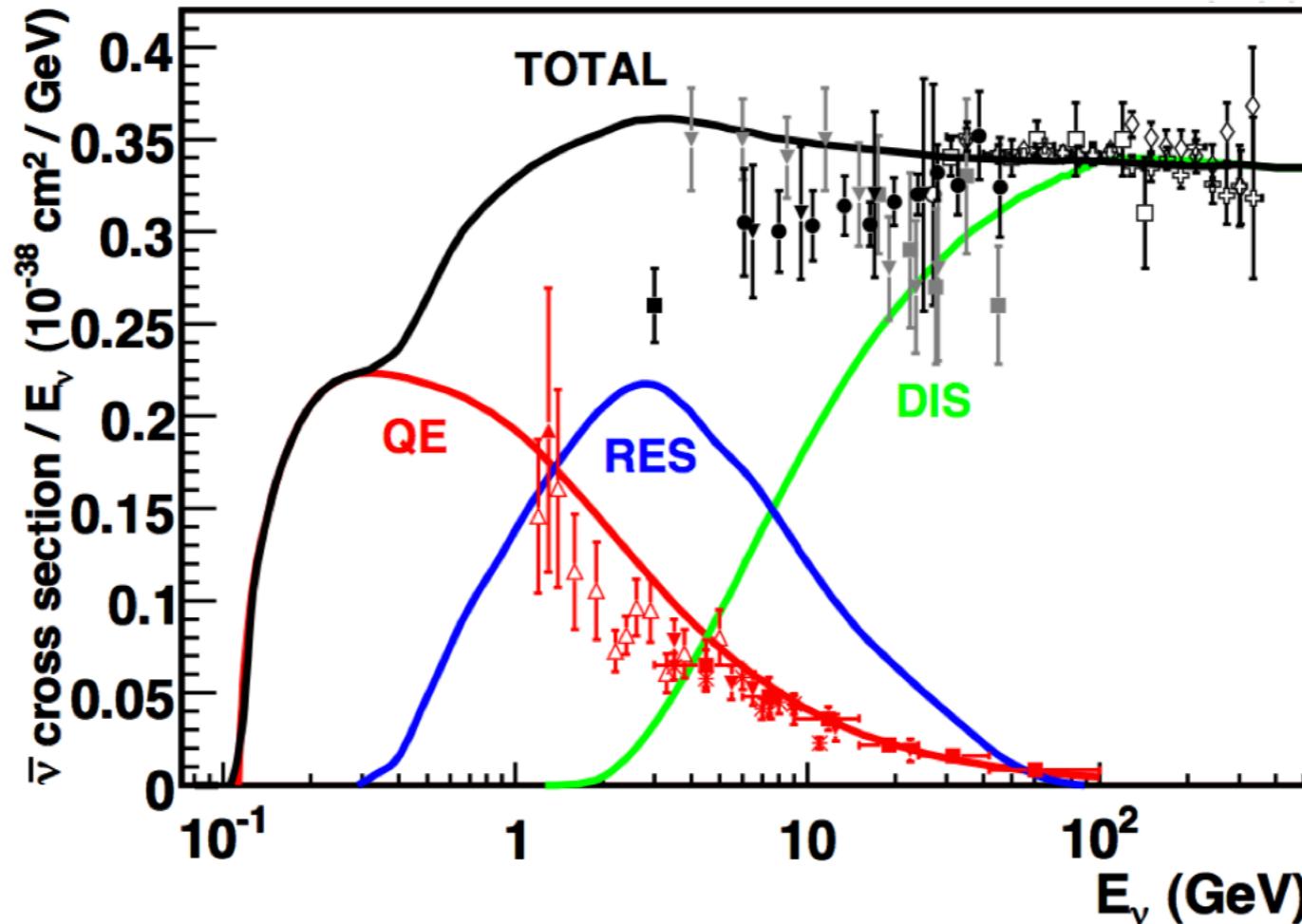


bigest flux systematic 1σ shift



blue: prediction with 1σ shift of the flux uncertainty
red: nominal spectrum

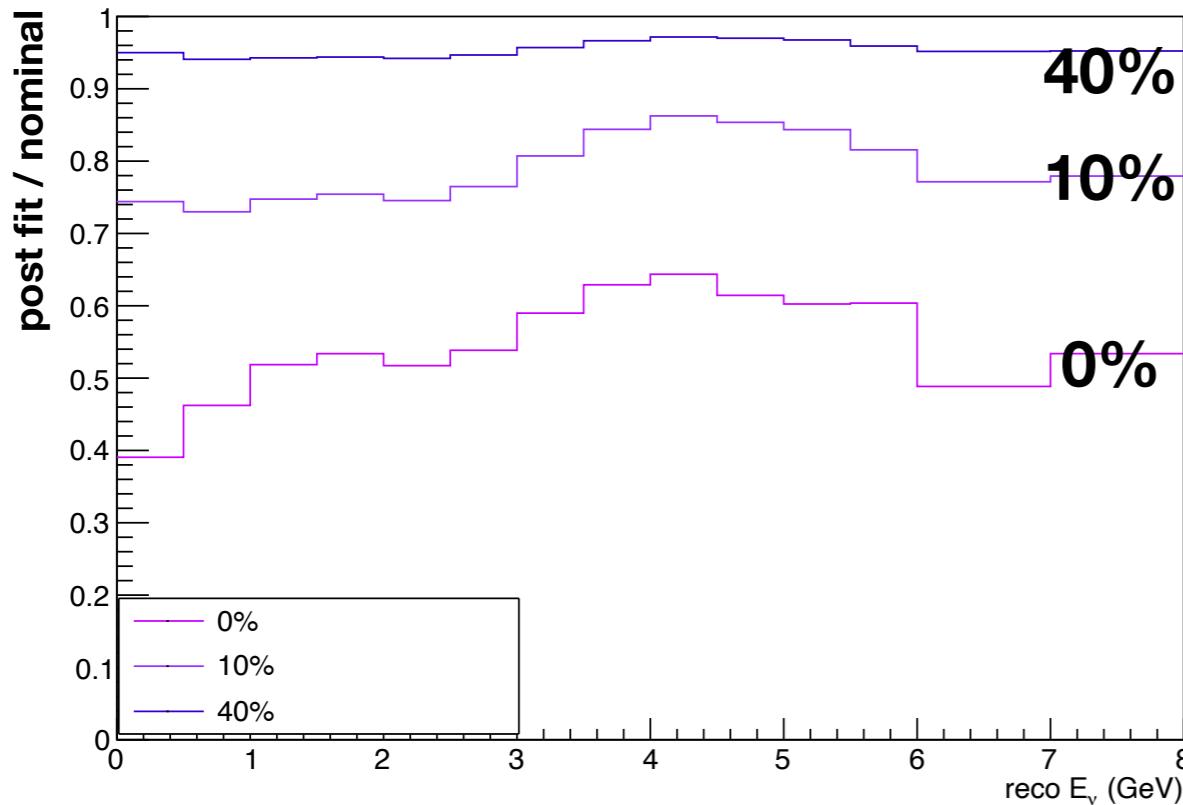
Low ν cross section uncertainty



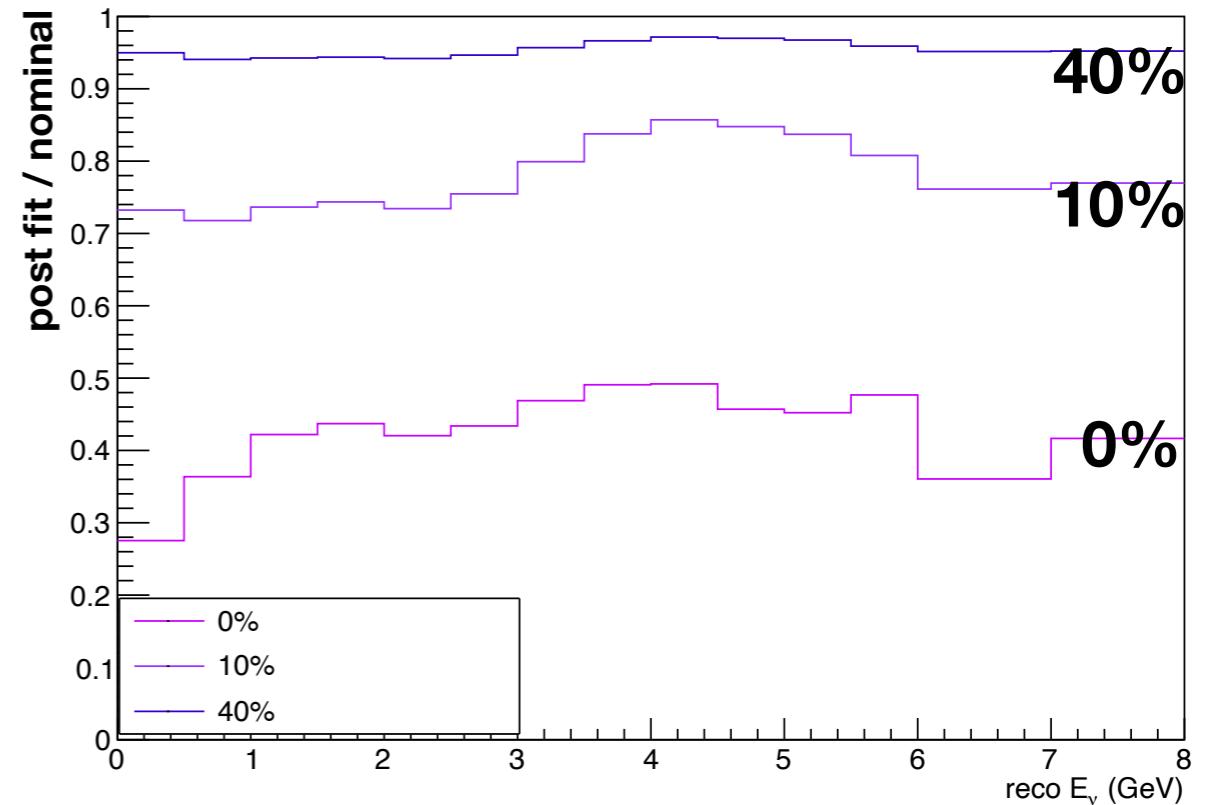
<https://arxiv.org/pdf/1205.2671.pdf>, Fig.4-8

- External anti neutrino CCQE cross section measurement uncertainty is 10~40%.
- Low ν cross section is expected to be flat, uncertainty is below 10%.
- As an example, low ν uncertainty can be less than 3%:
<https://arxiv.org/pdf/1201.3025.pdf>

Fitting result



1 year, 2.4×10^6



10 year, 2.4×10^7

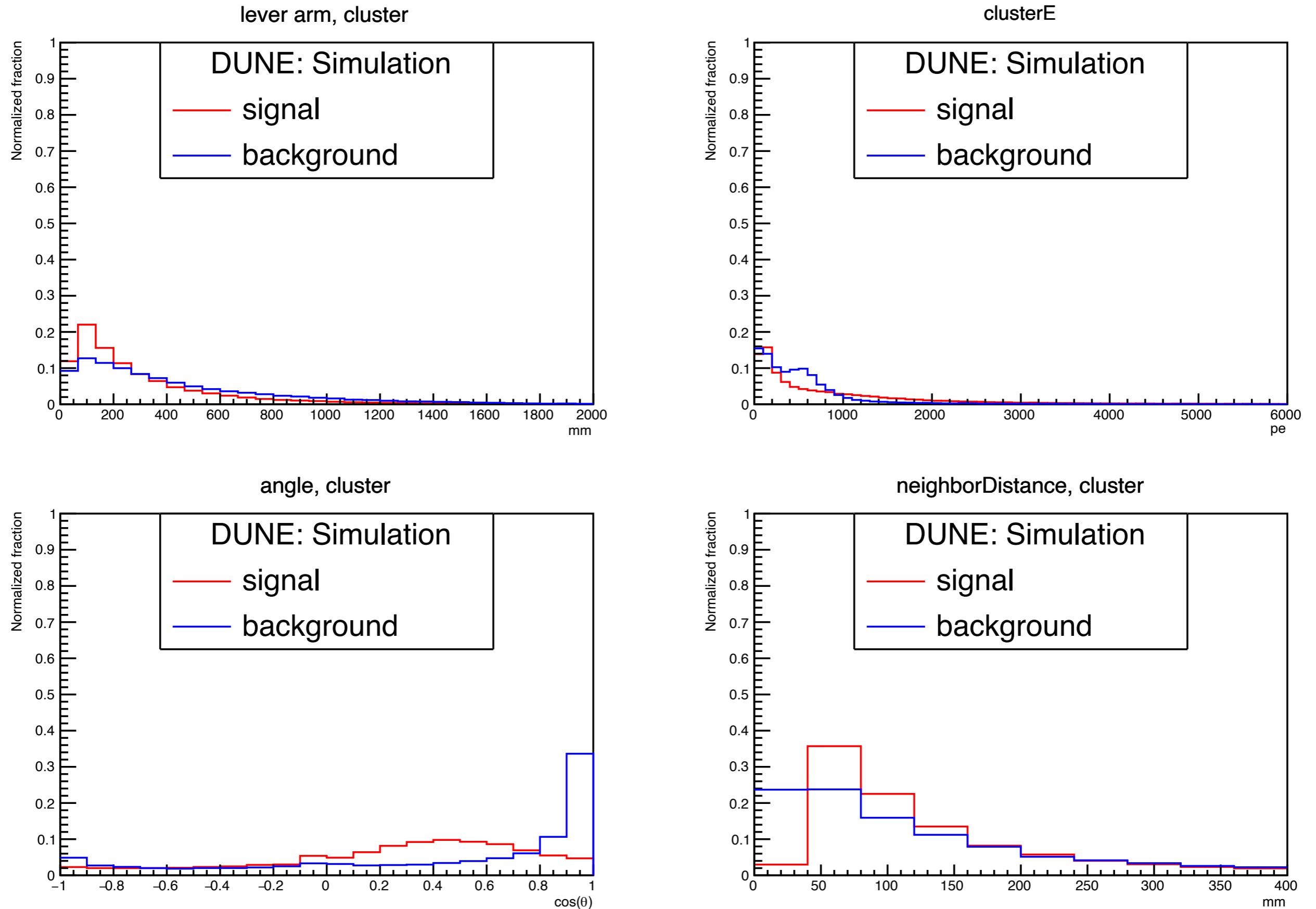
- Reconstructed $E_\nu = \text{reco muonE}$ (4% momentum smearing) + reconstructed neutronKE (time of flight).
- post fit / nominal for three (0%, 10%, 40%) low ν uncertainty.

Summary

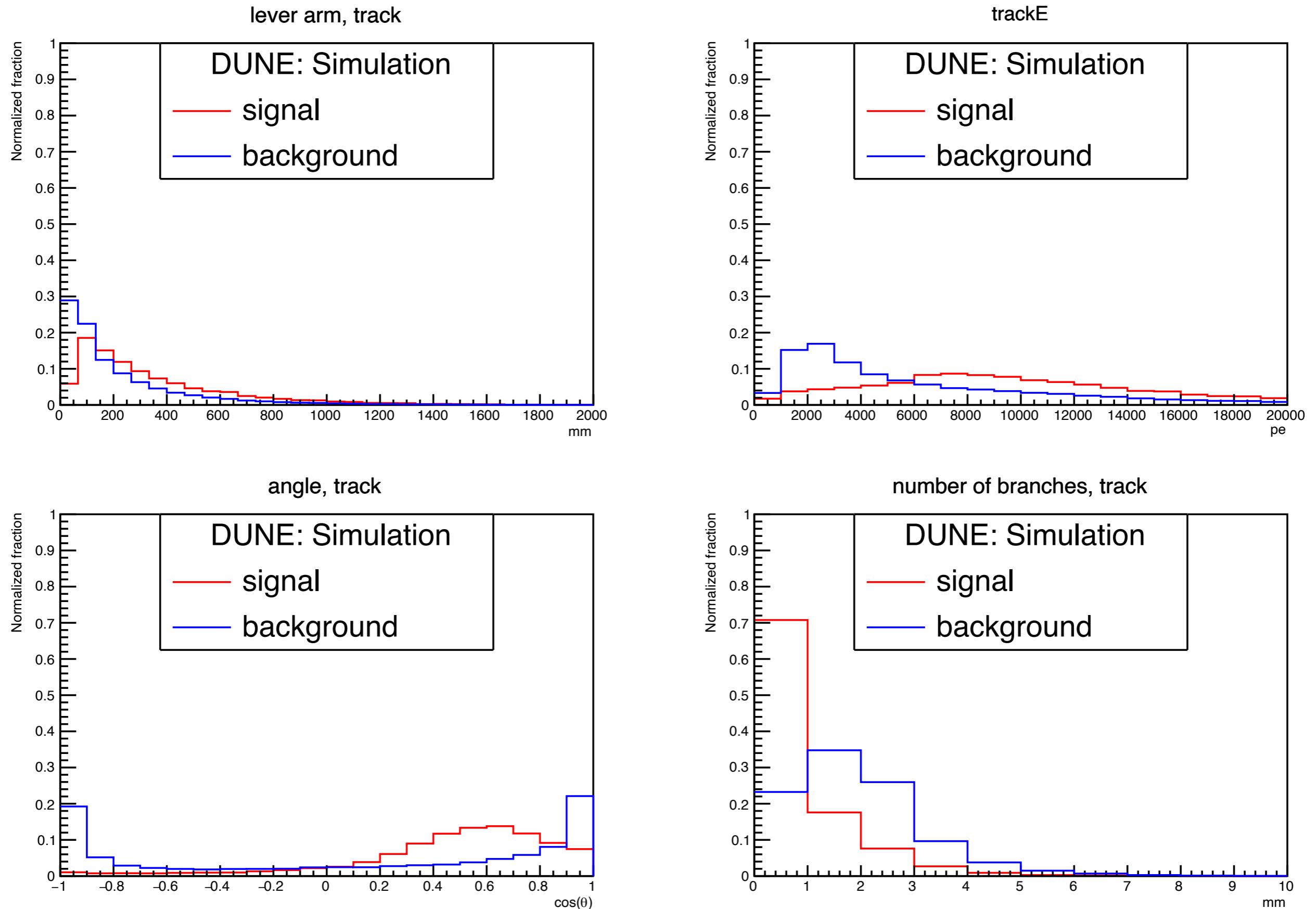
- We selected 90% purity of neutron signal sample in 31% efficiency with 1.5cm cube.
- We are developing fitting framework to extract the flux constrain for the low nu sample.

Back up

Variable distribution

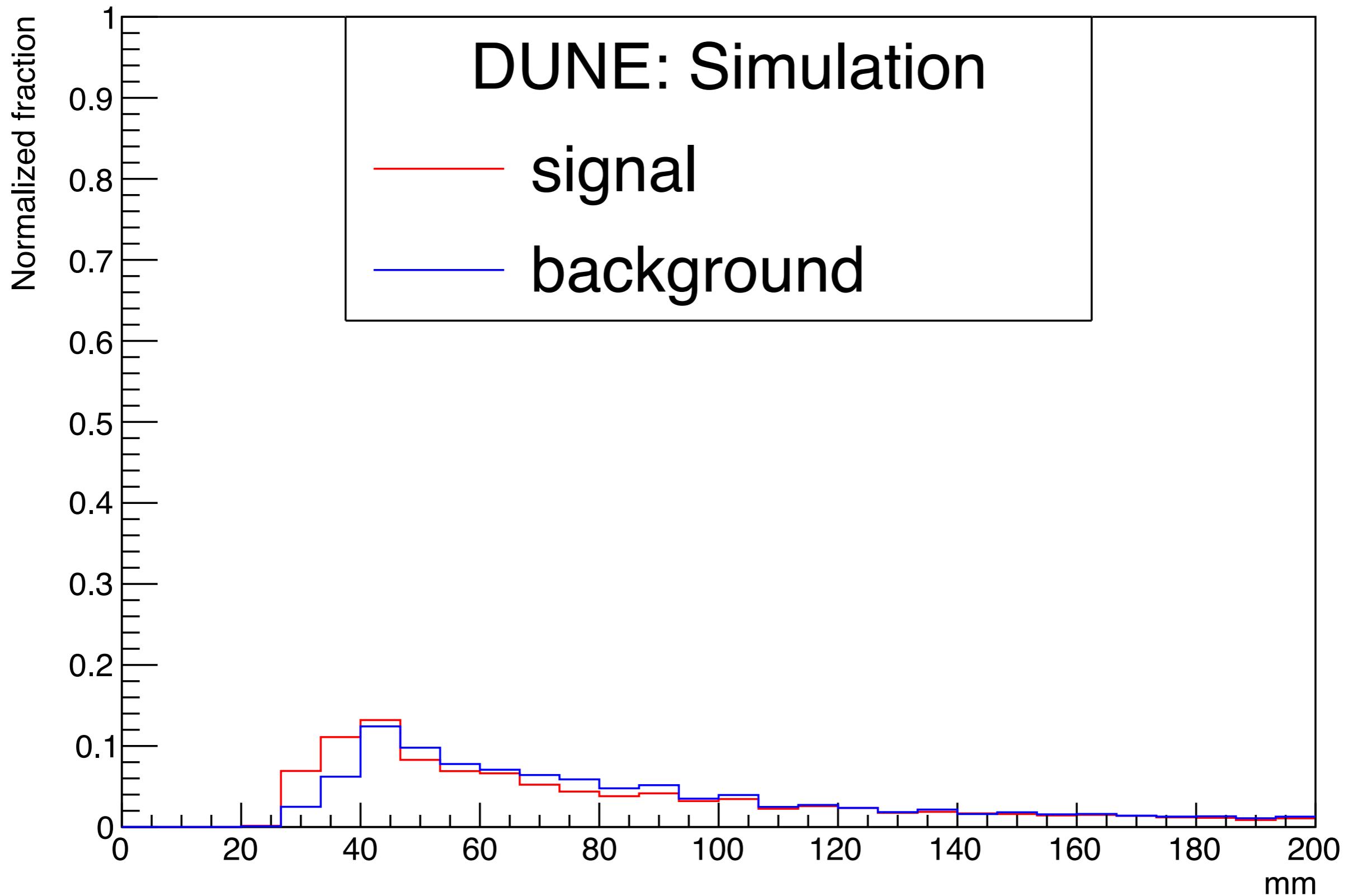


Variable distribution



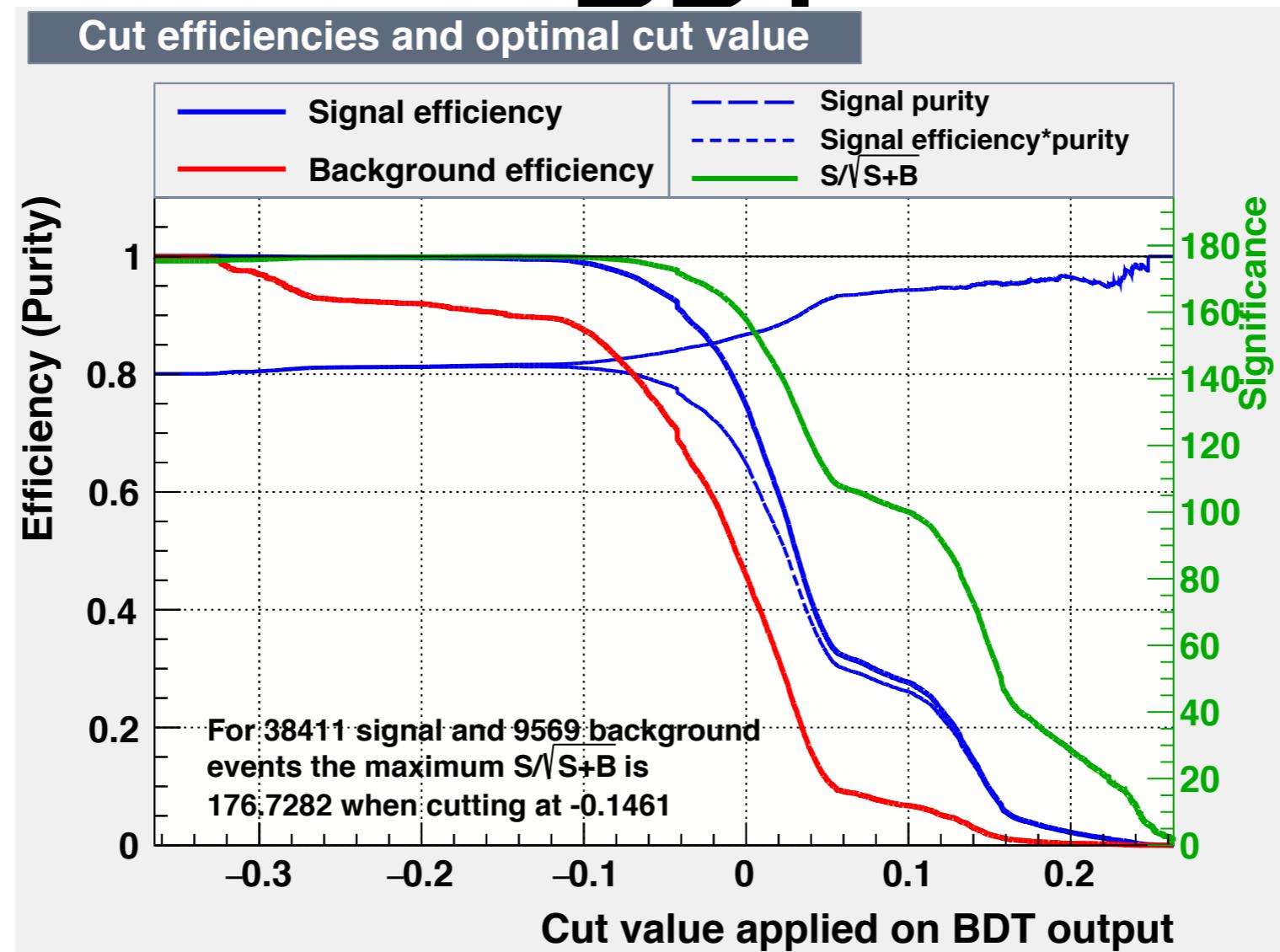
Variable distribution

track length, track



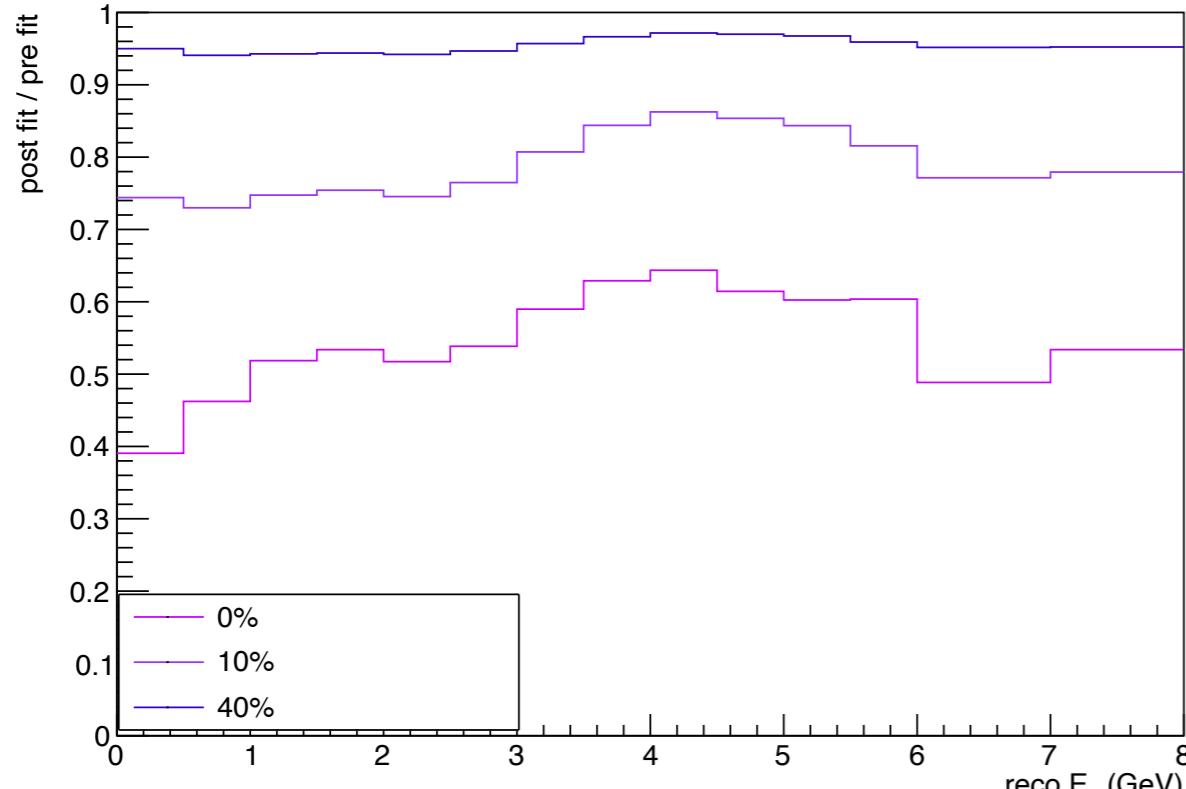
Signal selection

- BDT

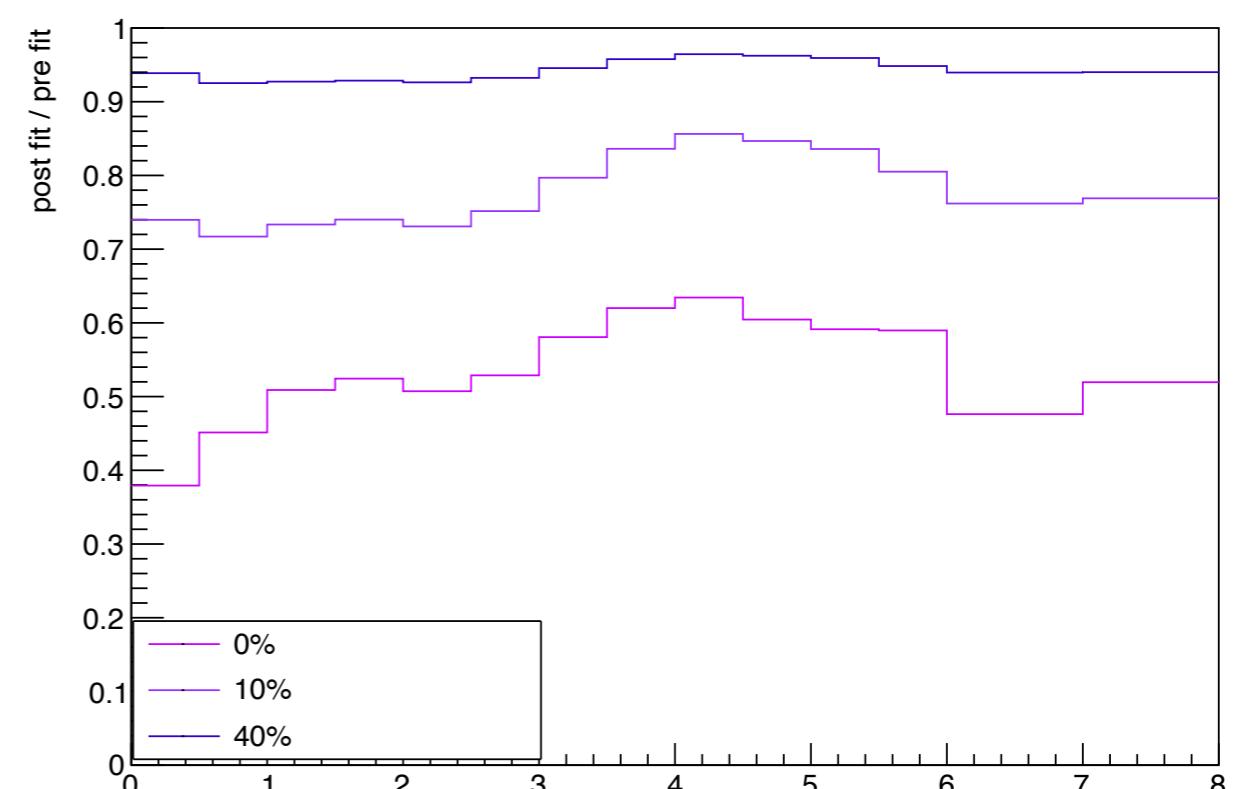


- Track purity 95% efficiency 23.0%, cluster purity 95% efficiency 25.7%.
- Combined efficiency is 25.2%, we are checking neutron phase space.
- After selecting low ν , the final selection efficiency is %.

Fitting result



1.5 cm cube



1 cm cube

True to reco neutrinoE

